Decentralized Secondary Frequency Control in an Optimized Diesel-PV Hybrid System

energynautics
solutions for sustainable development

Alice Turnell, Peter Schierhorn, Daniel Masendorf (Energynautics GmbH)

Kateryna Morozovska (KTH Royal Institute of Technology)

8th Solar Integration Workshop

Stockholm, October 17th 2018

MOTIVATION

INDONESIA
target:
23% RE in produced electricity by 2025

Challenge

- High RE integration in island electrical systems

Motivation

- Reduce generation cost and emissions

CASE STUDY OVERVIEW

REAL ISLAND
IN INDONESIA

0,8 MW, 3GWh load

Very Small Grid

100% Diesel based

0,21 EUR/ kWh

94500 L/month

12h/day supply

CUMMINS C900D5

CHALLENGE

High RE integration in island electrical systems

- Intermittent, non-dispatchable
- Typically no inertia contribution or participation in frequency regulation
- Islands:
  - To allow a high RE integration, RE must participate in frequency regulation
  - Unreliable communication channels for secondary frequency control
    - Alternative: PV Decentralized secondary frequency control

PROJECT GOAL AND METHODOLOGY

Goal

Feasible integration of a high share of RE into an island system (case study)

PHASE 1: CAPACITY EXPANSION

energynautics
solutions for sustainable development

Optimization Problem Structure

- **Parameters**
  - Equipment Costs
  - Generator minimum load limit
  - Load Profile Forecast
  - Expected Inflation and Nominal Discount Rate
  - RE Potential
- **Constraints**
  - RE target
  - Operating Reserve
- **Optimization Variables**
  - Installed Capacity of generators
  - LCOE and NPC
  - Fuel Consumption
  - % RE achieved
  - Generation Dispatch

Objective function: Minimize NPC

PHASE 1: RESULTS OF THE OPTIMIZATION PROBLEM

2025 Optimal Capacity Expansion

Diesel generator (kW) | PV System (kW) | Li ion (kWh) | Battery Inverter (kW)

PHASE 2: PV FREQUENCY CONTROL

energy**nautics**
solutions for sustainable development

PV's model combines:

- Allocated **reserve**
  - Reaction to underfrequency events
- **Decentralized** strategy
  - No communications required
- **Time-based** secondary frequency control
  - Lower error and oscillations
  - Return to reserve setpoint (control set time ends)

PHASE 3: FREQUENCY STABILITY ANALYSIS

energynautics
solutions for sustainable development

2025 Island grid modelled in PowerFactory

- Dynamic generator models
- Distributed PVs in 8 locations (reduce fluctuations)
- No ESS

Tests performed under high PV penetration (low inertia)

- Solar irradiance variations
- Disconnection of 30,1% of total load
- Disconnection of generation (1 PV plant, 1 diesel)
- Disconnection of 1 large feeder (37,5% of PV generation; 37,5% of total load)

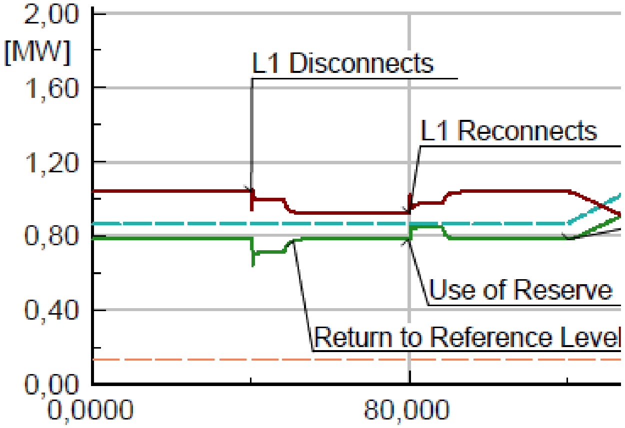
Sensitivity analysis on

- Control parameters → Obtain fast response with lower oscillations

PHASE 3: RESULTS OF FREQUENCY STABILITY ANALYSIS

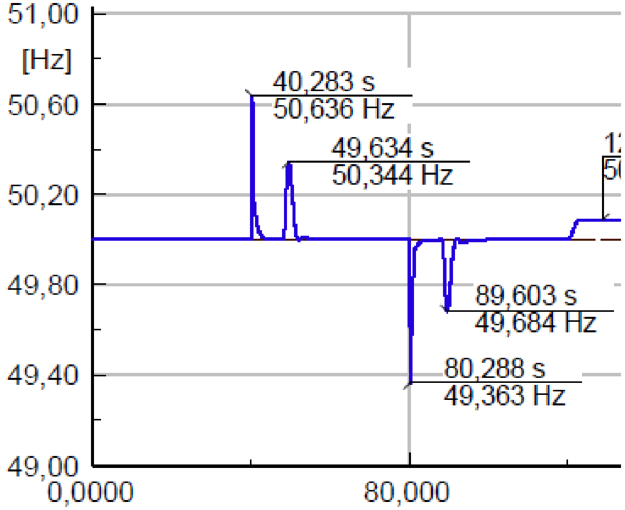
Overview of the system response

6,5% load trip/reconnection, **600 W/m²**



← Active Power

- PV Total [MW]
- PV MPP [MW]
- Diesel Total [MW]
- Diesel Minimum [MW]

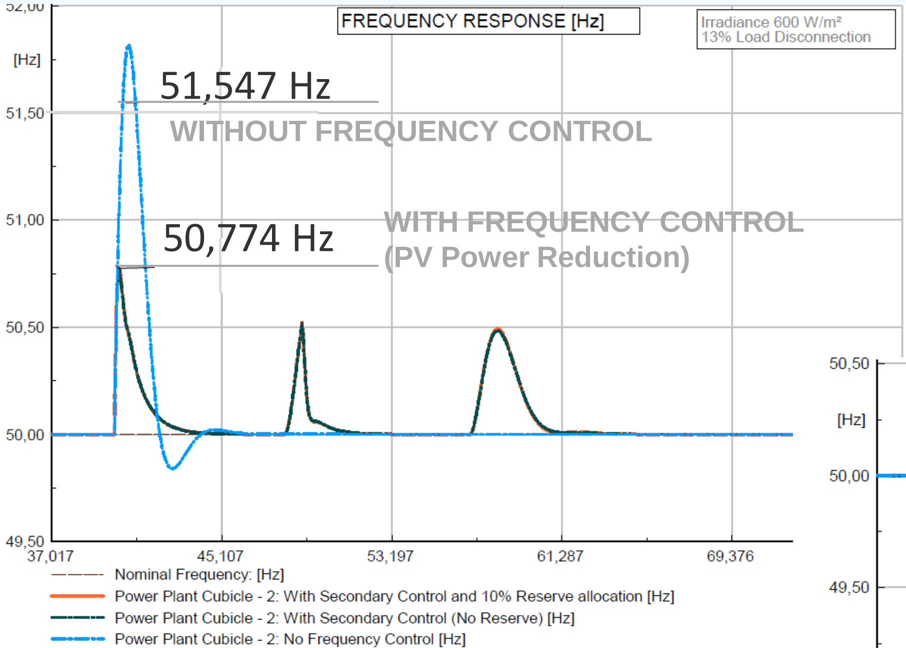


← Frequency response

- Nominal Frequency [MW]
- Frequency [MW]

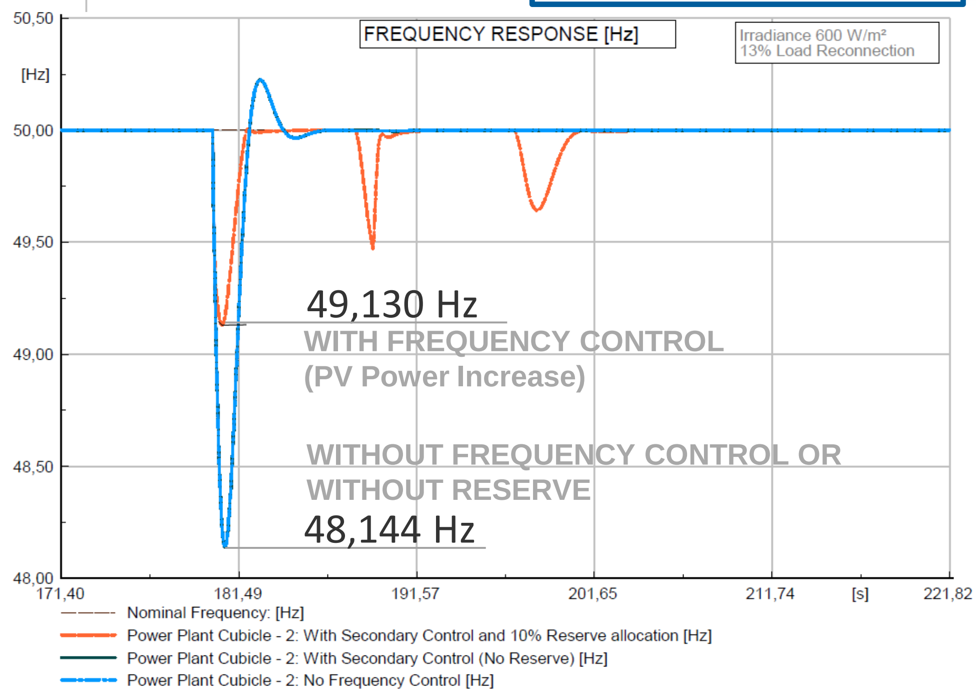
PHASE 3: RESULTS OF FREQUENCY STABILITY ANALYSIS
Comparison of Control Operation Modes

13% load trip and reconnection, Irradiance 600 W/m²



LOAD DISCONNECTION

LOAD RECONNECTION



PHASE 3: RESULTS OF FREQUENCY STABILITY ANALYSIS

energynautics
solutions for sustainable development

Test Conclusions

- System remains stable (low inertia):
  - Without ESS
  - After a 30,1% load disconnection (IFD 52,8 Hz cleared restored within 2 seconds)
  - After a diesel trip (IFD 47,4 Hz, diesel supplying 35% of load)

    (acceptable for small islands)

- Reserve levels help improve the frequency Nadir

- Distributing the PVs improves the frequency stability

CONCLUSIONS

- A high share of RE generation can be integrated in case study island system, meeting RE target and with an economically optimal generation mix.

- The proposed control strategy:
  - Improved frequency response
  - Maintained maximum PV penetration possible (continuous attempt to reach reference)
  - Restored frequency without communication between generators

- Results as lessons learned for the expansion of similar islands

FUTURE DEVELOPMENT

energynautics
solutions for sustainable development

- DSM to reduce curtailment
- Decentralized frequency control as a backup strategy
- Reserve allocation: risk and economic analysis
- Further Grid Integration Analysis (e.g. Voltage Stability, Reliability)

Project continues…

THANK YOU FOR YOUR ATTENTION!

a.turnell@energynautics.com